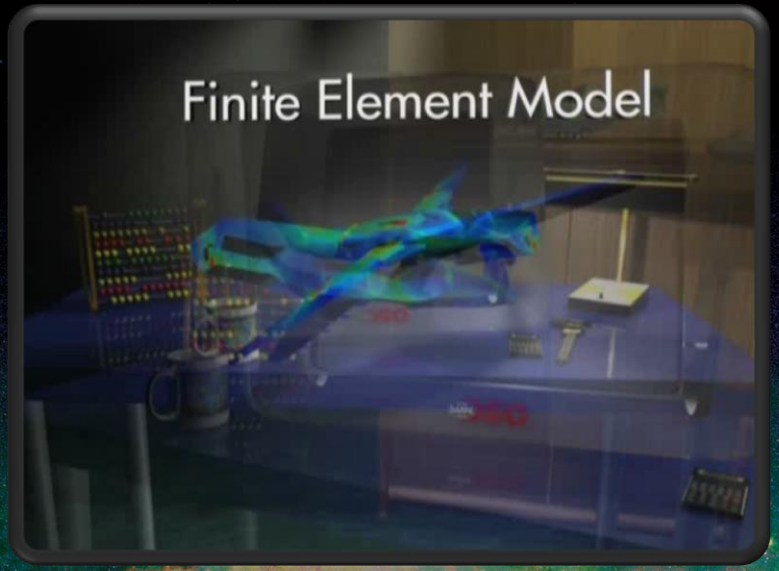
National Aeronautics and Space Administration

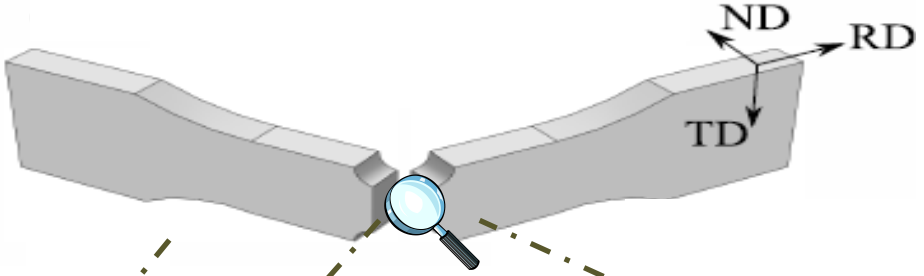
DDSIM Level 3: Damage Science

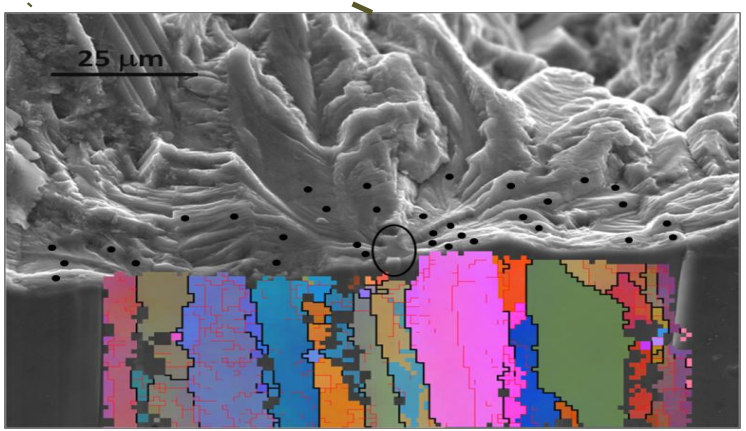


Jacob D. Hochhalter, NASA Langley

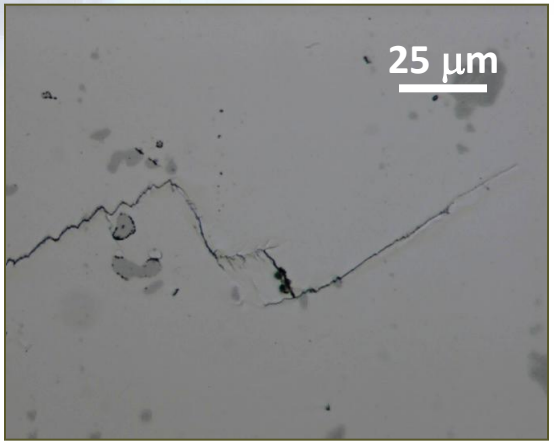
DDSIM Level 3 Objective

To better understand and prognose the distribution of fatigue behavior as it relates to inherent material inhomogeneities.

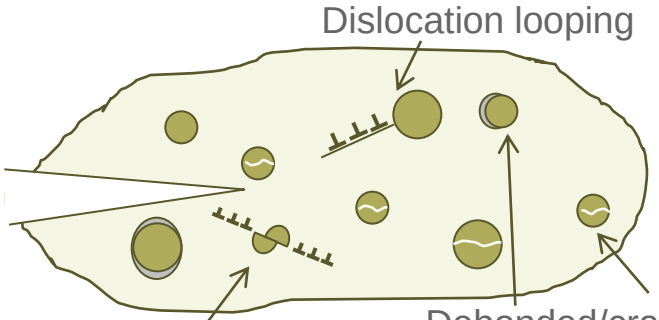


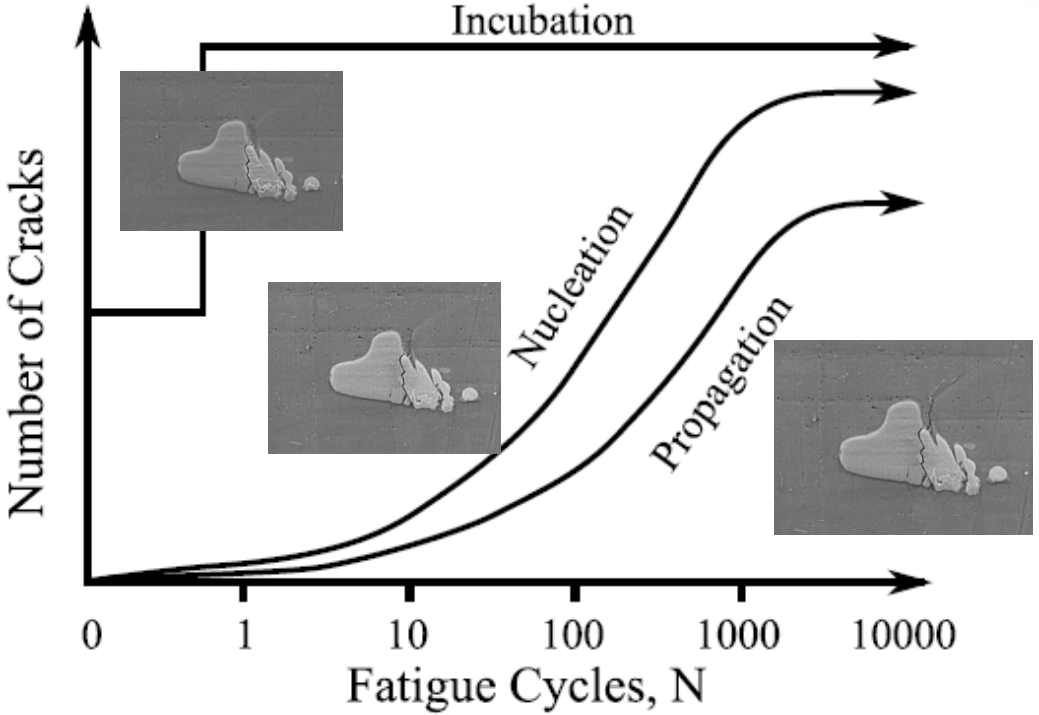


Microstructurally Small Fatigue Cracking

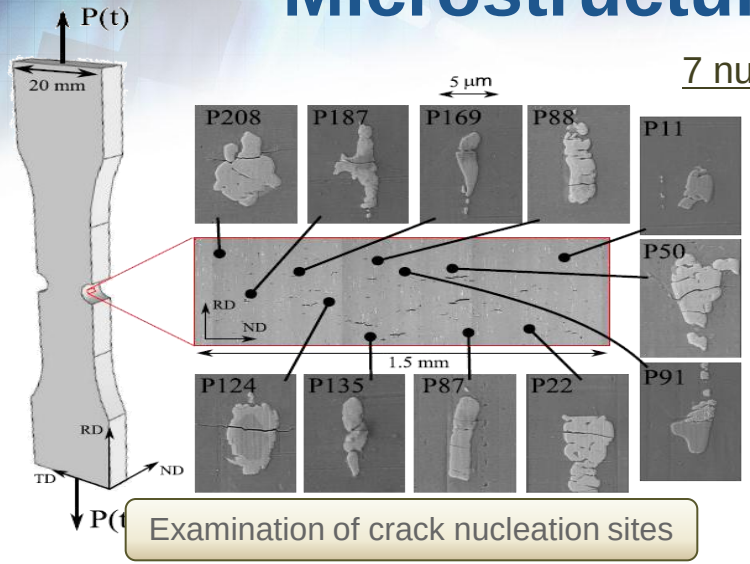


- Identify and isolate key microstructure features





Microstructure-Replication Modeling

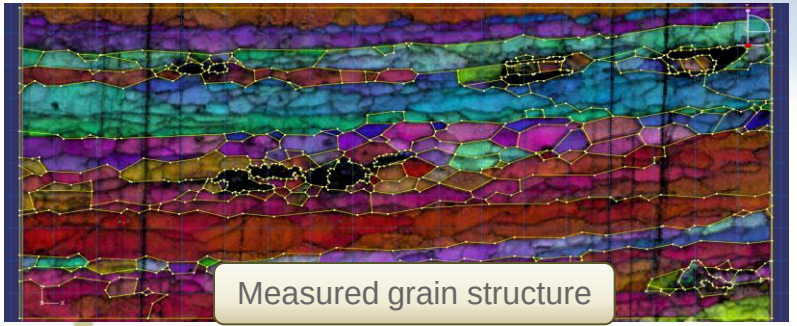


Examination of crack nucleation sites

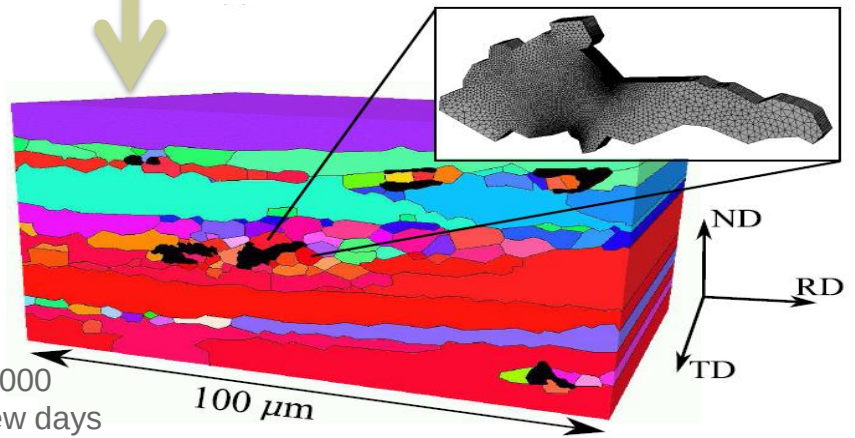
7 nucleated by 3000 cycles

4 never nucleated

Why?



Measured grain structure



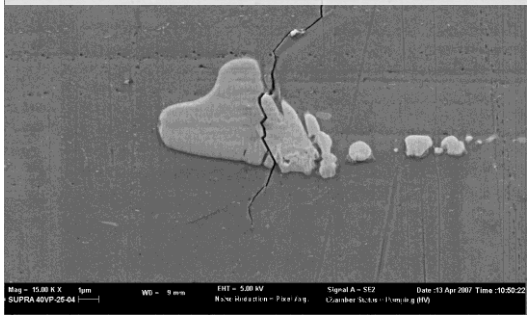
Replication of measured grain structure

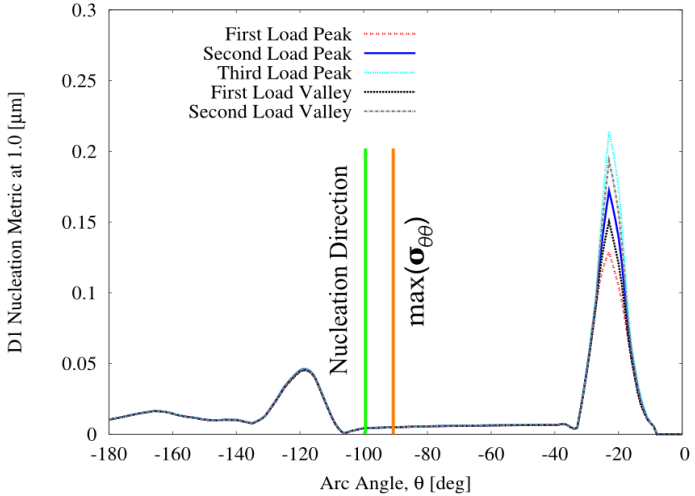
HPC enables simulation of microstructural mechanics: necessary to develop models that describe observed variability

Can require upwards of 4000 cores for a few days

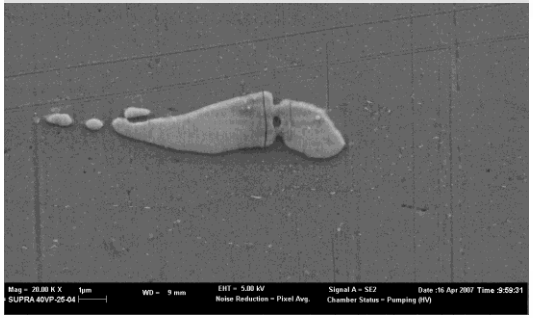
Compare & Contrast Results

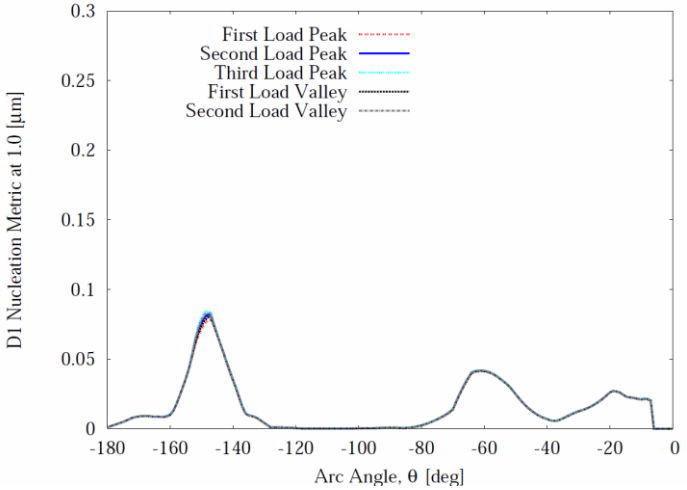
Nucleated



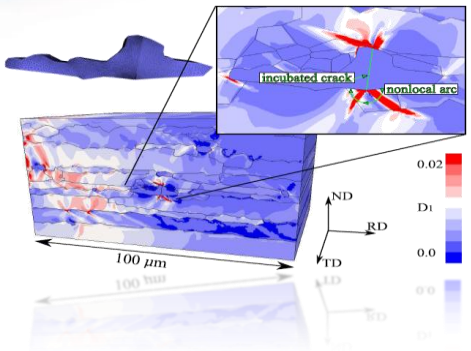


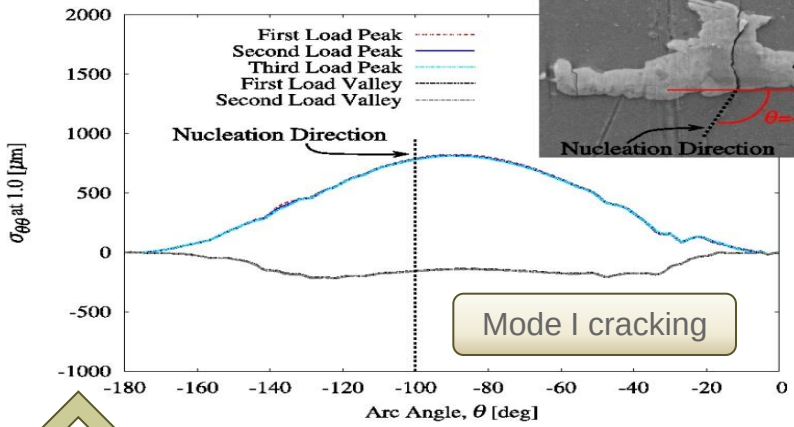
Did Not Nucleate

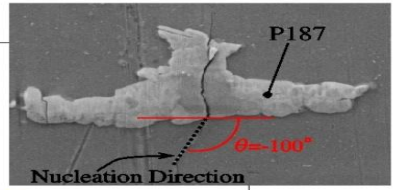




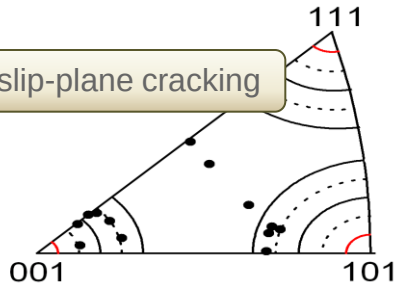
Validating Computed Results



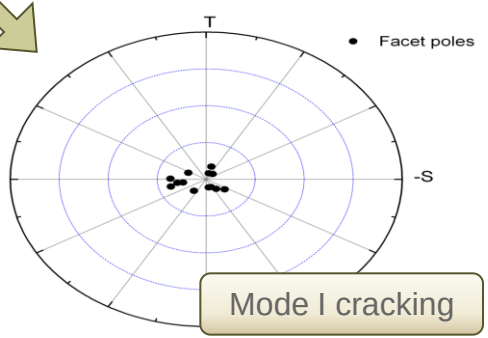




Mode I cracking



No slip-plane cracking

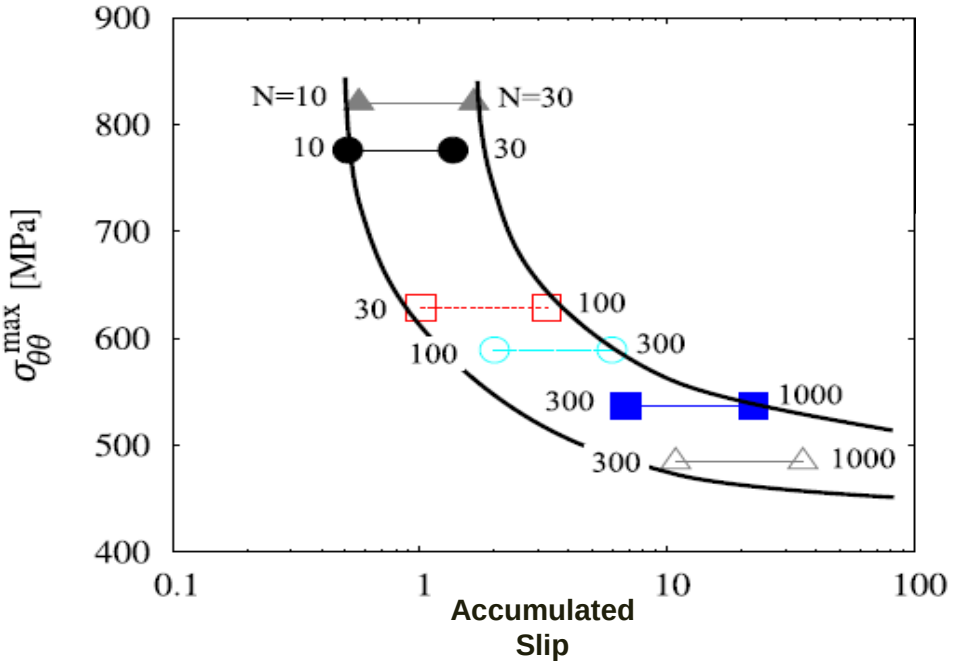


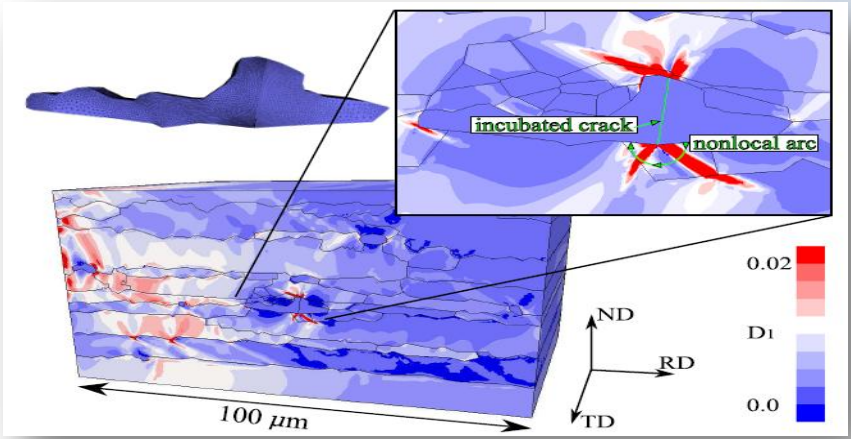
Mode I cracking

Comparing simulation results with recent measurements provides validation and corrects errors in previous models

Semi-Empirical Nucleation Model

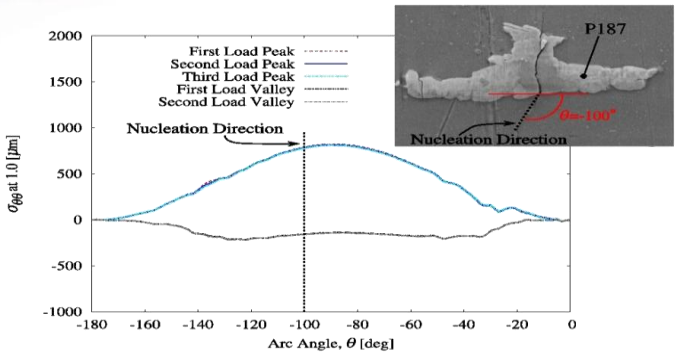
The stress required to drive nucleation reduces with accumulation of slip

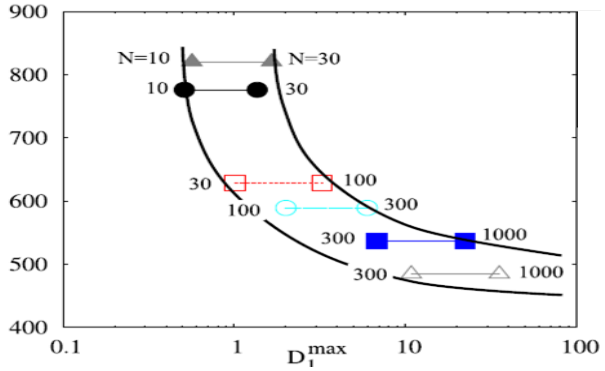




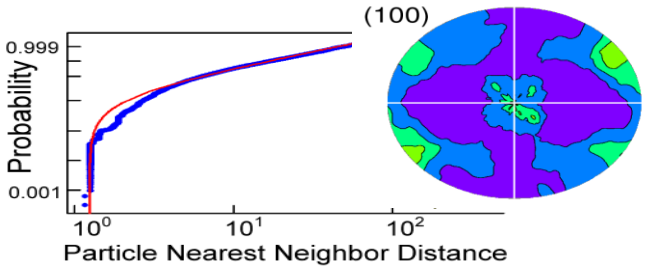
HPC simulation of several microstructures led to a model that describes observed variability

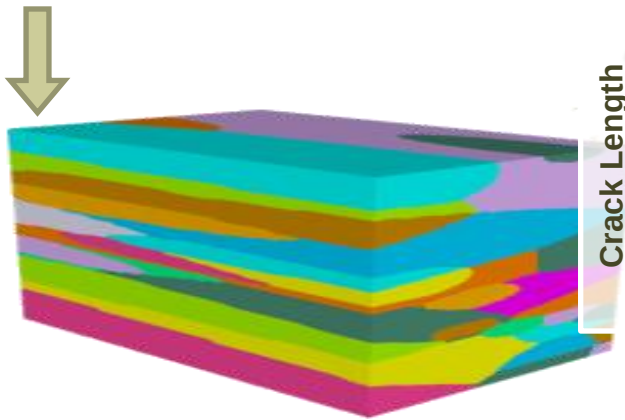
Implement Semi-Empirical Cracking Models

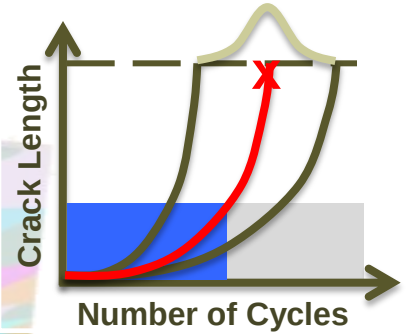




Modeling the mechanics that underpin observed variability enables design of ultra-durable materials



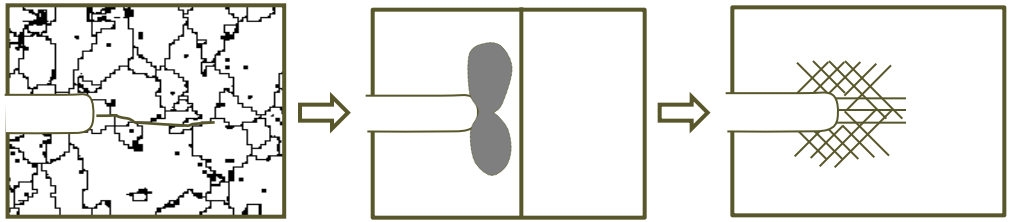




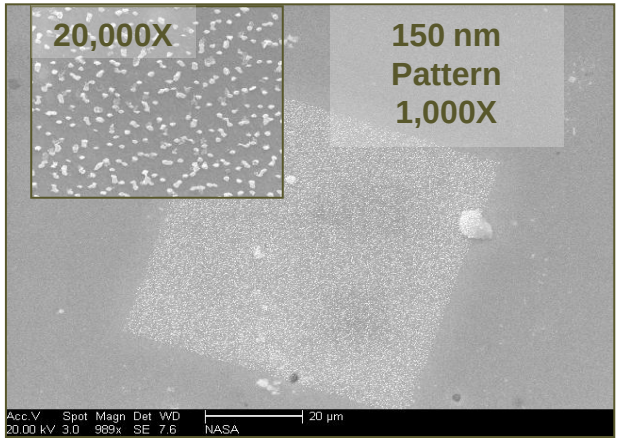
Statistical realization of microstructure

Improved Fidelity with Damage Science

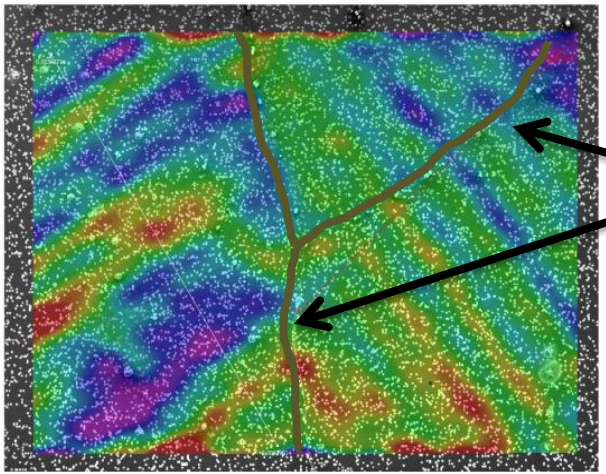
Complex alloys **Simplified (cleaner) single/bi- crystals**



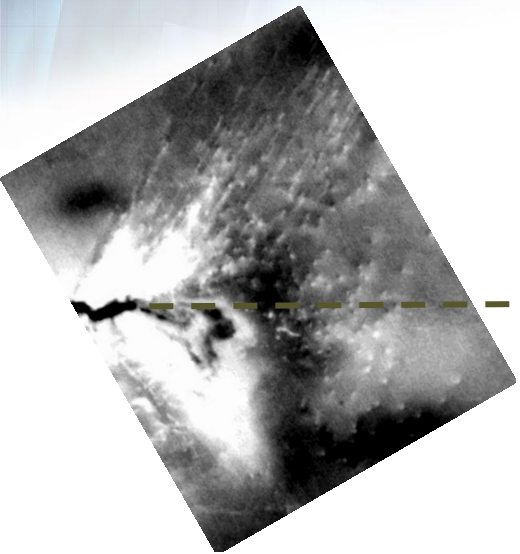
High resolution VIC 2D ® in ESEM



Displacement resolution = O(10 nm)
Strain resolution =10^{-4}

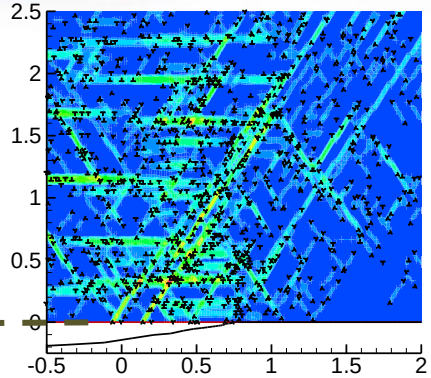


Improved Fidelity with Damage Science



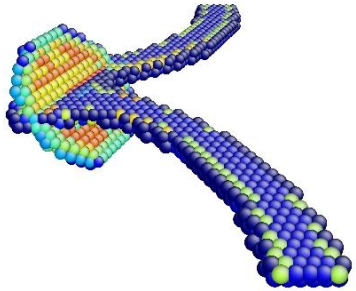
Secondary Electron Image of Crack Tip in NiAl

Crimp et al.



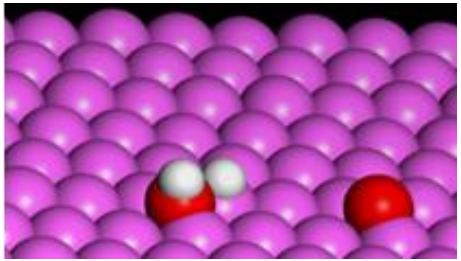
Dislocation-Crack Interaction

Curtin et al.



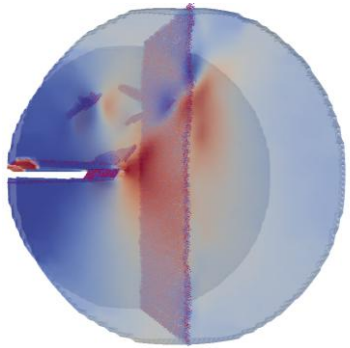
Dislocation-Precipitate Interaction

Warner et al.



Water-Crack Surface Interaction

Kelly et al.



Crack–Grain Boundary Interaction

Yamakov et al.